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TITLE "NEUTRON MEASUREMENTS IN THE FIELD-REVERSAL-C(FRX-C) MAGNETIC COMPRESSION EXPERIMENT"

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Neutron Measurements in the FRX-C/LSM Magnetic Compression Experiment*

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Introduction

Neutron measurements are being pursued as an ion temperature diagnostic in the FRX-C/LSM Magnetic Compression Experiment. One can easily see that the d-d neutron emission is a sensitive measure of ion heating during adiabatic magnetic compression of FRCs. The reaction rate may be written as $R = (1/2)\, n\, N \langle\sigma v\rangle$, where n and N are the deuterium density and inventory. The fusion reactivity varies as $\langle\sigma v\rangle \propto T^{5.6}$ for T = 1 keV. For adiabatic compression, $n \propto B^{1.2}$ and $T \propto B^{0.8}$ so $R \propto B^{5.7}$ in the absence of losses. The neutron yield is also sensitive to the time duration that the plasma remains near its peak temperature.

Neutron Detectors

We have tried two types of neutron activation detectors to measure the yield in FRX-C/LSM. The first consists of a 0.25 mm rhodium foil wrapped around a geiger tube and located inside a Cd-shielded moderator.[1] The rhodium is activated by thermal or epithermal neutrons and then β-decays with a 42.3 s half-life. The decays are counted for 60 s starting 0.1 s after a compression shot. The second is based on the $^{75}As(n,n')^{75m}As$(0.304 MeV) reaction and consists of an epoxy casting of arsenic powder surrounding a plastic scintillator.[2] The arsenic metastable state decays through gamma emission with a 17 ms half-life. The gammas are detected by a large plastic scintillator (20 cm ϕ × 10 cm) and photomultiplier tube (12.7 cm ϕ) and counted for 50 ms starting 5 ms after compression. The time-resolved neutron emission is measured by viewing the plastic scintillator with a second smaller photomultiplier tube operated in current mode.

The rhodium counter was located 1 m from the axis of the compression coil at z=4.3 m. It was calibrated *in situ* by activating it to steady state with a ^{252}Cf neutron source (2 MeV average energy) placed inside the compression coil and then counting the decays after the source was quickly removed. This calibration indicated that the rhodium counter is about 3.3 times more sensitive than expected from the original d-d neutron calibration performed by Ekdahl.[1] Based on the results of other tests performed in a variety of scattering geometries, we can attribute about a factor of two sensitivity enhancement to the scattering and/or partial moderation caused by the massive aluminum compression coils. The remaining sensitivity enhancement may be caused by the difference in the neutron spectrum or by other unknown effects. The coils are also expected to modify the spatial distribution of the neutron source to resemble a diffuse source with the dimensions of the coil itself. Based on a calculation of detector response to such a diffuse source (including the angular sensitivity of the detector), the rhodium counts were systematically increased by 6%. An additional correction is needed whenever the FRC is not axially centered in front of the rhodium counter. The estimated uncertainty in the neutron yield measurement is a factor of two.

The arsenic counter was placed about 4 m from the compression coil to avoid interference by the dc magnetic field. The calibration technique used for the rhodium could not be used for the arsenic because of its short half-life; instead the original published calibration has been tentatively used. Multichannel scaler analysis of the arsenic count rate showed an

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initial rapid decay with about a 5 ms time constant and which contributed to the counts in the nominal counting interval. These early counts can be attributed to room-scattered neutrons.[3] When the delay before counting was increased to 10 ms, the neutron yield estimated from the arsenic and rhodium counters were in approximate agreement. Since the net counts obtained from the arsenic counter were three times smaller than from the rhodium counter, we have not made further use of the arsenic data.

Results

The measurements reported here were obtained using target plasma formed under reduced-field source conditions.[4] The initial FRC parameters at the start of compression were $r_s = 14.0 \pm 0.8$ cm, $B_w = 2.83 \pm 0.20$ kG, $\bar{n} = (0.48 \pm 0.07) \times 10^{15}$ cm^{-3}, $T_i + T_e = 348 \pm 85$ eV, and $T_e = 76 \pm 10$ eV.

The neutron yield was observed to increase rapidly with compression field (Fig. 1). The scaling is $Y \propto B^4$, which is less rapid than that predicted for the neutron rate during adiabatic compression. The maximum neutron yield was about 2.5×10^8 for 15.5 kG field.

The integrated plastic scintillator signal was compared with neutron yield on a shot-by-shot basis (Fig. 2). The linear relationship shows that the plastic scintillator is primarily observing neutrons and is used to calibrate the scintillator output for neutron rate (3.0×10^{16} neutrons/s/A).

The time evolution of compression field and neutron rate are shown in Fig. 3. The neutron rate increases rapidly with magnetic field until the FRC is disrupted near peak field by the n=2 rotational instability.

Together with density and volume, the neutron rate at various times during compression can be used to infer the ion temperature. This neutron ion temperature T_n can be compared with the ion temperature T_i inferred from pressure balance and Thomson scattering measurements (Fig. 4). For the purpose of this comparison the electron temperature is estimated from the empirical scaling $T_e(\text{eV}) = 32B^{0.86}$ obtained from Thomson scattering measurements during compression.[4] This comparison shows that there is reasonable agreement between T_n and T_i. However there is a tendency for T_n to exceed T_i when T_i is less than 0.8 keV, which needs further study. Nevertheless, these measurements show that substantial ion heating up to 1 keV has been obtained during magnetic compression experiments.

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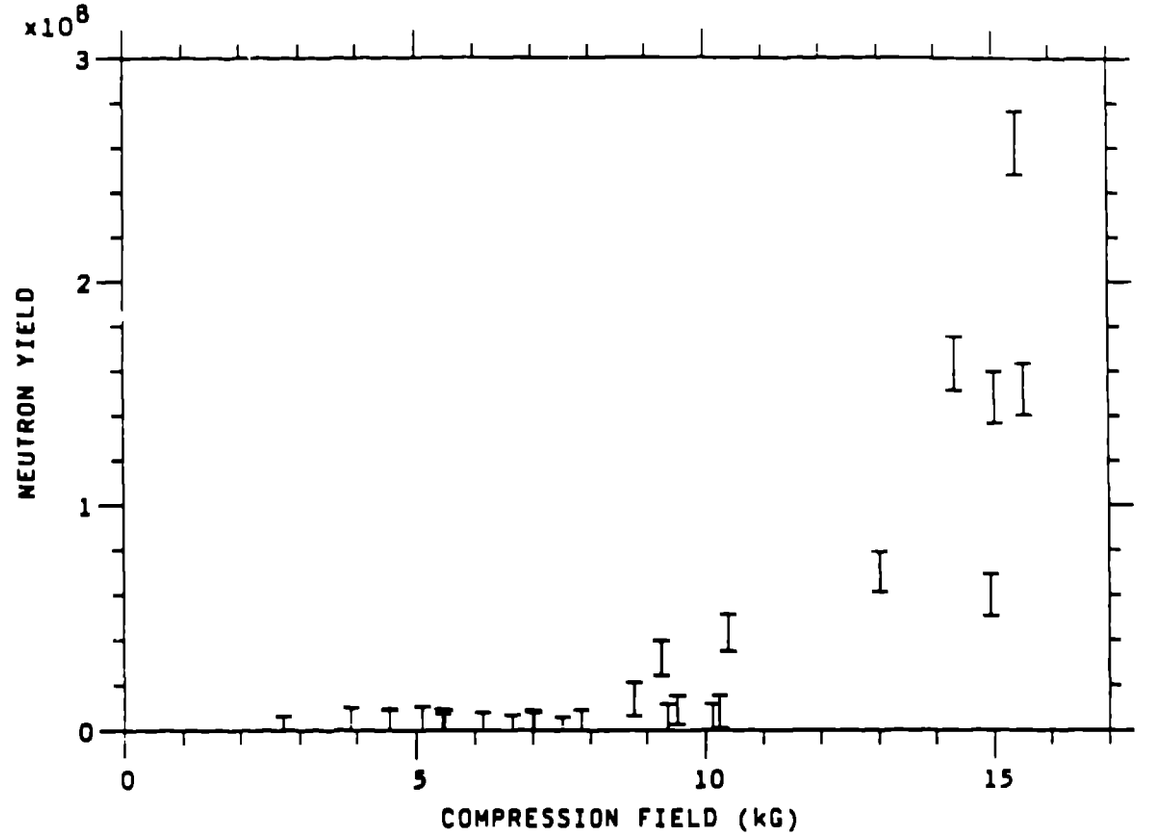

Fig. 1 Variation of neutron yield with magnetic field measured 40 μs after the start of compression.

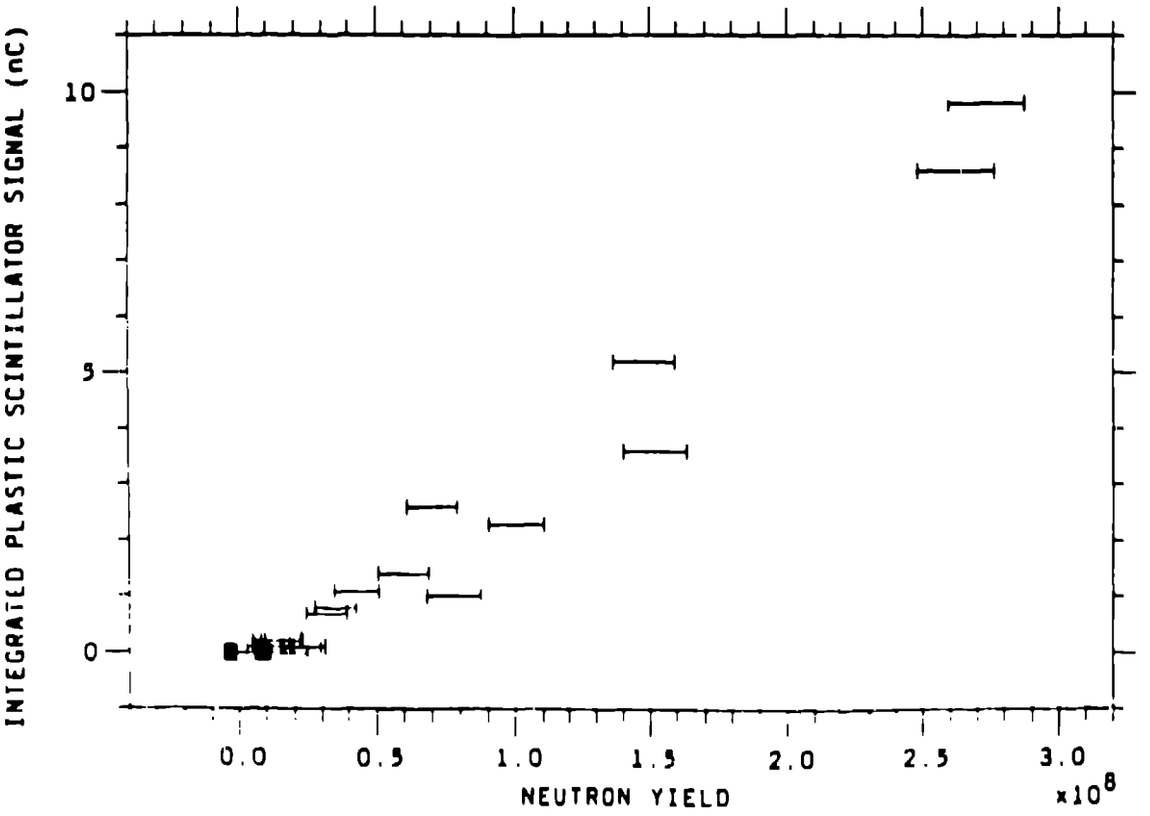

Fig. 2 Variation of integrated plastic scintillator signal with neutron yield

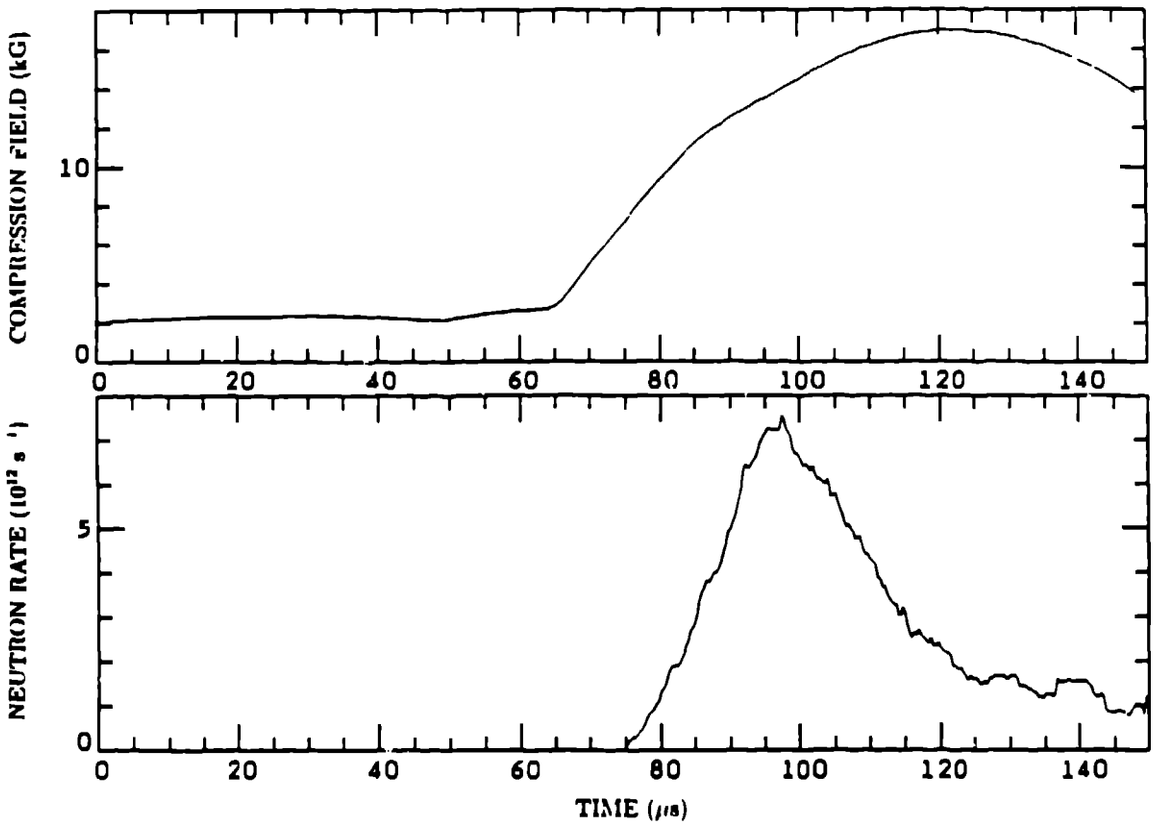

Fig. 3 Time evolution of compression magnetic field and neutron rate.

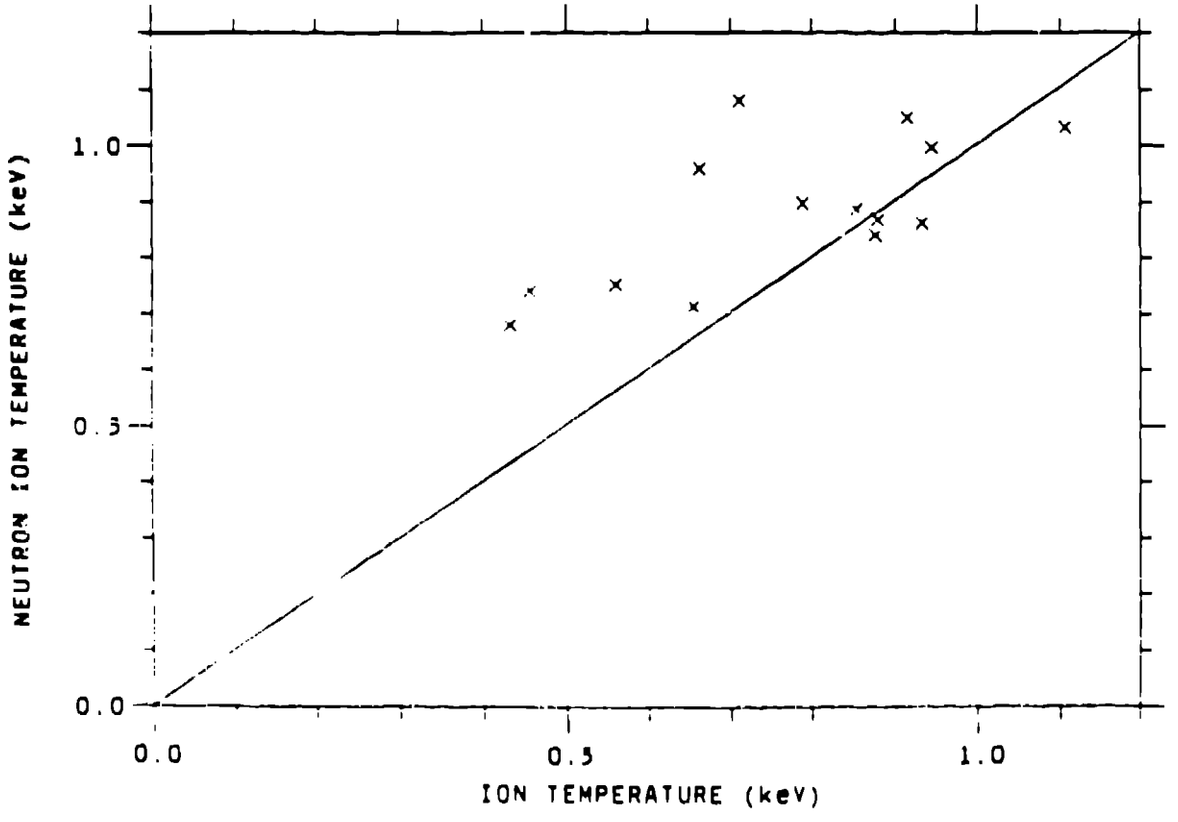

Fig. 4 Comparison of ion temperature inferred from neutron emission with